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# INSTITUTION OF PRODUCTION ENGINEERS

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## CONTENTS

| | Page |
|---|---|
| ARMORIAL BEARINGS OF THE INSTITUTION (Frontispiece) ... ... ... | 129 |
| HOW TO KEEP OVERHEADS WITHIN BOUNDS, by F. Theodorson, with report of Discussion, Nottingham Section... ... ... ... ... ... | 132 |
| MEETING OF THE COUNCIL, NOTTINGHAM (photograph) ... ... ... | 150 |
| SPOT WELDING, by C. W. Leng, A.M.I.P.E., F.R.S.A. with report of Discussion, London Section ... ... ... ... ... ... ... | 151 |
| PRODUCTION ENGINEERING ABSTRACTS ... ... ... ... ... ... | XXI |

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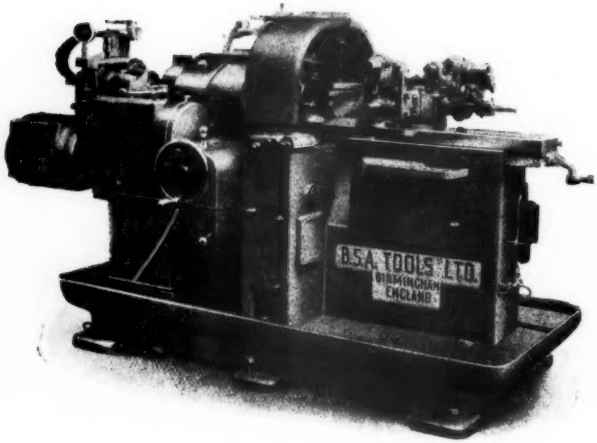


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## Armorial Ensigns of the Institution of Production Engineers.

Granted to the Institution, 28th February, 1939, by the Kings of Arms of the College of Heralds (Garter, Clarenceux and Norroy) under Warrant of the Earl Marshal of England and by virtue of the Letters Patent of their several Offices.

Printed by the Institution's Printing Department.

# THE ARMORIAL BEARINGS OF THE INSTITUTION

FACING this page is a reproduction in colours of the Armorial Bearings granted to the Institution. The official document conveying the Grant is elaborately engrossed on parchment about 15 in. by 21 in. in size. It is enclosed in a handsome casket covered with red leather on which the Royal Crown and Monogram, G.R. VI, are embossed in gold in several places. At the top left-hand side of the document the Arms, as granted, are depicted. Across the head of the document are the Ensigns of the three Kings of Arms, and, in metal containers suspended by blue ribbons from the base of the parchment, are their Seals of Office.

The following is the wording of the Grant :—

> TO ALL AND SINGULAR to whom these Presents shall come Sir Gerald Woods Wollaston Knight Commander of the Most Honourable Order of the Bath, Knight Commander of the Royal Victorian Order Garter Principal King of Arms, Sir Arthur William Steuart Cochrane Knight Commander of the Royal Victorian Order Clarenceux King of Arms, and Algar Henry Stafford Howard Esquire, Companion of the Most Honourable Order of the Bath, Commander of the Royal Victorian Order, upon whom has been conferred the Decoration of the Military Cross, Norroy King of Arms, Send Greeting. WHEREAS *Richard Hazleton*, General Secretary to the Institution of Production Engineers, hath represented unto The Most Noble Bernard Marmaduke, Duke of Norfolk, Knight of the Most Noble Order of the Garter, Earl Marshal and Hereditary Marshal of England and One of His Majesty's Most Honourable Privy Council, that an Institution was founded on the twenty sixth day of February one thousand nine hundred and twenty one and Incorporated on the first day of July One thousand nine hundred and thirty one under the Companies Act 1929 by the name of *The Institution of Production Engineers* with the object, interalia, of promoting the science and practice of production engineering. That the Memorandum and Articles of Association of the said Institution provide that its income and property shall be applied solely towards the promotion of the objects of the Institution as therein set forth and that the management of the said Institution shall be vested in a

Council to be elected as provided in the said Articles of Association. That the Council of the said Institution of Production Engineers is desirous that the Seal of the Institution shall contain fit and proper Armorial Ensigns duly assigned under legal authority, he therefore on behalf of the Council hath requested the favour of His Grace's Warrant for Our granting and assigning such Armorial Ensigns as may be proper to be borne and used by the Institution of Production Engineers on Seals Shields or otherwise, the said Arms to be borne and used by the President of the said Institution and by his successors impaled with his and their own family Arms during his and their terms of Office. AND FORASMUCH as the said Earl Marshal did by Warrant under his hand and Seal bearing date the fifteenth day of July One thousand nine hundred and thirty seven authorise and direct Us to grant and assign such Armorial Ensigns accordingly. KNOW YE THEREFORE that We the said Garter Clarenceux and Norroy in pursuance of His Grace's Warrant and by virtue of the Letters Patent of Our several Offices to each of Us respectively granted do by these Presents grant and assign unto *The Institution of Production Engineers* the Arms following that is to say: *Gules issuant from a section of the dial of a Timepiece in base Or a cubit Arm proper winged Argent holding a Torch Gold enflamed also proper, a Chief of the third trellised Sable.* And for the Crest, on a Wreath of the Colours, *A demi Bull Sable gorged with a Collar Or pendent therefrom a Hunting Horn Gules garnished and stringed of the second and holding between the forelegs a Geneva Wheel proper* as the same are in the margin hereof more plainly depicted to be borne and used for ever hereafter by The Institution of Production Engineers on Seals, Shields or otherwise, the said Arms to be borne and used by the President of the said Institution and by his successors impaled with his and their own family Arms during his and their terms of Office the whole according to the Laws of Arms. IN WITNESS whereof We the said Garter Clarenceux and Norroy, Kings of Arms have to these Presents subscribed Our names and affixed the Seals of Our several Offices this twenty eighth day of February in the third year of the Reign of Our Sovereign Lord George the Sixth by the Grace of God of Great Britain Ireland and the British Dominions beyond the Seas King, Defender of the Faith, etc., and in the year of Our Lord One thousand nine hundred and thirty nine.

(Signed) GERALD W. WOLLASTON-GARTER (Seal).

(Signed) ARTHUR COCHRANE—CLARENCEUX (Seal).

(Signed) ALGAR HOWARD—NORROY. (Seal).

" In all ages and in all quarters of the world," records the article on Heraldry in the *Encyclopaedia Britannica*, " distinguishing symbols have been adopted by tribes or nations, by families or by chieftains." That is still true to-day. For years the Institution has used as its Seal a symbolic design for the artistic worth of which no great claims could be made. It seemed right, therefore, that if distinguishing symbols were to be used at all they should be properly designed and duly authorised in conformity with the laws of heraldry.

It was a matter of no little difficulty to reconcile what the representatives of the Institution wished to have as symbols in the Grant of Arms with what the College of Heralds was prepared to concede. The Pursuivant, Rouge Dragon (Mr. E. N. Geijer) was very patient but very firm. Special thanks are due to Lord Sempill for his part in the negotiations and to Mr. W. H. Butler, M.I.P.E., and Mr. Scott-Giles for their contributions to the design and their efforts to find the right solutions for the many problems that arose. Good design was an important consideration. That and the somewhat inflexible laws of heraldry had to be reckoned with when devising symbols appropriate to the modern science of production engineering. The result appears to be much better than might have been expected under the rather difficult circumstances.

A prominent feature of the Coat of Arms is the " crested helm." Above a helmet, resting on a torse or " wreath " of twisted red and gold silk, is a black " demi-bull." The bull is a symbol of strength and also commemorates the association with the Institution of its President, Viscount Nuffield, and of Lord Austin, Past-President, in both of whose Armorial Bearings a bull is one of the details. From a gold collar round the neck of the bull is slung a hunting horn. This commemorates our Deputy-President, Lord Sempill, from whose Arms this detail is taken. The Geneva wheel held in the forelegs of the bull as a badge typifies multiple machine production, a factor of prime importance in the work for which the Institution stands.

Surrounding the crested helm, and linking it with the shield, is the " mantling " of red and gold.

The squared portion of the shield above the red ground symbolises control by measurement, while the section of the clock face at the base of the shield symbolises time control. The hand stands for the human element, the torch for learning, and the wings for progress. The gold in the shield symbolises the wealth created by production engineering.

In the scroll below the shield is the motto—" Vires Acquirit Eundo." This is a quotation from Virgil, meaning, literally, " He gathers strength in the going," which might be freely translated as " Forging Ahead."

# HOW TO KEEP OVERHEADS WITHIN BOUNDS

*Paper presented to the Institution, Luton and Nottingham Sections, by F. Theodorson.*

IT is very pleasing to see from your syllabus that your Institution up and down the country is receiving speakers on the subject of expense control, because, although it may superficially appear that this subject is somewhat outside the usual scope of your Institution's work there is, in fact, a great deal in common. I think I can put it that the whole scheme of budgetary control of expense can be described as the " planning " of the commercial and financial departments, and is in very much the same relationship to these departments as the planning department is to production. One of the main drawbacks in present-day large-scale production is that it inevitably tends towards the growth of water-tight departmentalisation. We are all so bound up with our own departmental problems that there is always the danger of developing a " parish pump " mentality which is definitely bad from the point of view of the firm, and industry as a whole. If this talk to-night has the effect of helping us to understand what the other fellow is driving at—and particularly if it helps to get rid of the very natural thought that the budget and everything connected with it is just a nuisance, it will have served a very useful purpose.

Let me start off by a plain statement of the truism that the purpose of all industrial undertakings is the making of a profit. It is probably unfashionable to express it thus baldly, and I don't wish in any way to belittle the vary considerable ethical influences which have modified the policies of large numbers of firms from time to time, but the cold fact remains that in the final analysis the continued existence of any commercial undertaking is dependent upon a balance on the right side of the profit and loss account. We may have a well laid out factory, a keen buying department, an efficient sales force, and even the best set of production engineers there are, but unless the net result of all their labours is a profit, it is only a question of time before we are out of business.

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*Luton, 6 December 1938; Nottingham, 27 January, 1939.*

To take this lesson in elementary economics a stage further. In the make-up of the selling price of any product we have four elements: (*a*) Productive labour; (*b*) production material; (*c*) on-cost or burden; (*d*) profit, totalling up to (*e*) selling price.

Now I want to suggest that under present-day conditions the selling price, the costs of productive labour, and productive materials, are very largely established for us by circumstances which we can only control to a limited degree. If this statement can be substantiated then obviously the control of burden or expense becomes of tremendous importance, and may ultimately determine whether the firm continues as a healthy financial unit, or finishes up in Queer Street.

Let us see how far this premise is true as regards selling price, and here I think my home ground—motor cars—is an extremely good illustration. Obviously, in establishing the price of a car the manufacturer has to be guided very considerably by other producers' prices for similar vehicles. If the general trend of prices for a 14 h.p. car is around the £230 mark, a manufacturer who is out for volume knows perfectly well that his price must be established within a very few pounds of this figure. There are a relatively few people who will pay quite a bit more for the privilege of indulging their own particular fancy, but not enough to upset the general conclusion with regard to volume lines. In the same way there are a number of smaller manufacturers who are making a nice living in supplying this "non-standard" market, but of the 146,000 new car registrations in Great Britain during the last six months 131,000 were the products of ten firms who all come within my "price-class" competitive market. This general theory is now so well-established that it is possible to use "price-class" basis as a reasonably reliable index in forecasting the market potentialities of any new model.

The same general principle can be applied to amost any article in the "quantity-produced" category—radios, clothes, furniture, or what-have-you. The history of new inventions is monotonously similar—in the early stages it is possible to sell in a severely limited market at fantastically high prices (witness motor cars and radio) but as more people come into the business the tend inevitably is towards the regularity of prices at much lower levels but at much higher volume. It may be possible for a time to evade this regulation by such artificialities as monopolies, price-rings, etc., but the buying public are not long in finding ways and means of getting round such restrictions. I contend, therefore, that in general it is true to say that in almost any "big-volume" line the manufacturer has to recognise that his selling price is more or less fixed for him before he starts on the job.

Next, to deal with the productive labour element, I think I need spend only a few minutes in getting your agreement to the conclusion that wage-rates are almost entirely determined by outside influences. Trade Union agreements, Trade Boards' regulations, etc., cover an ever-widening field, and even where these do not apply, the tendency must be for the "open shop" to find itself short of skilled labour if rates lower than the recognised district rates are offered. It may be possible in times of wide-spread unemployment to get men to take on a job at a copper or two less than the standard rate, but I should imagine that nowhere in the world does the rule of getting what you pay for apply more strongly than in this department. You may have a strong supervision, a keen time study department, and all that goes with it, but if you have a labour force working under a grievance, then your production is bound to suffer, either in quantity or quality.

This point is so well recognised that the more highly organised firms (and in general the most successful) have developed a high wage policy—not so much from altruistic motives, but mainly as a matter of good business. I am, of course, recognising that the number of productive man-hours in any job can be widely varied according to the equipment available and the degree of efficiency of the planning department, but as regards the actual price you have got to pay per man-hour I suggest that the individual organisation is largely circumscribed by external forces.

Thirdly, to take a quick look at the productive material situation. Here my point with regard to the manufacturer being largely at the mercy of external circumstances is transparently obvious. Given an efficient buying department you can, in general, say that the price you have to pay for your materials will be roughly the same as your competitors, and the inescapable law of supply and demand puts very close limits on the savings which can be effected in this field.

All that I have said so far has been to emphasise the importance of efficient control of the one remaining element of cost, namely, Burden. I think it is true to say that although industry as a whole has for a long time been prepared to spend a great deal of time and money on the supervision of labour and material costs, it has only recently begun to recognise the great possibilities of an efficient system of budget expense control. This system has been adopted by a considerable number of British concerns during the past few years, but there are still very large sections of industry where expense control is probably not given the attention it deserves.

Having to some extent made the case for budget control, let us pass on to a consideration of the actual workings of the system. Your expense budget has to fulfil two major functions. In the first place it will build up the approved "standards" of expenditure

on every expense item in each department, and thereby serve as a gauge against which the actual spendings are constantly checked.

Secondly, it will establish for every productive division a theoretical burden rate to be applied to the productive labour in that division in building up your cost of sales. With the trend of modern production methods all being towards a continuous decrease in the number of productive hours per piece produced, and an increase in the relative expenses, the correctness or otherwise of your burden rate is of vital importance in the compiling of Make or Buy studies, development projects, and shop planning generally. A saving in productive times has something imposing about it, but can easily involve a net loss to the firm unless the less spectacular background of expense and burden rate is given due consideration.

An easy illustration of my point here is in machine feeds and speeds. I suppose that any production engineer could walk into his shop to-morrow and make a very impressive saving on his machining times by pushing up his feeds and speeds, but the effect on his "secondary" tool costs and machine breakdowns might be disastrous. A soundly established expense budget and burden rate would quickly bring anything of this kind to light.

It is usual (though not essential) to prepare the Expense Budget on an annual basis, and it is, of course, closely tied up with the Sales Budget, which in turn gives us the anticipated productive labour. Right from the beginning it is desirable to spread the responsibility for the Budget as widely as possible and the ideal would probably be for every individual who is in the position to spend money to have to prepare his own budget. The value of decentralisation cannot be stressed too much—we have to recognise that a charge-hand or other minor official in signing a requisition or a job card is drawing on the firm's resources in precisely the same way as a higher official signing cheques. The spreading of responsibility for the Budget can help to bring this point home and it also has certain psychological advantages. Obviously the outlook of a departmental manager towards a budget which he himself has originated is likely to be much better than to an appropriation drawn up entirely by other departments. There is also the point that in the preparation of his budget the departmental manager probably has to do a little more delving into financial details of his own department than he does in the usual routine, and this annual financial "stock-taking" may bring to light quite a lot of things that he didn't know too much about before.

Another important point is that the Budget and the whole of the expense accounting procedure shall be broken down as finely as possible. The building up of an account and the investigation of overruns is, of course, simplified considerably when the individual account covers only a limited number of items of expense. A shop

foreman, for instance, would be interested in quite a number of accounts—his standard tools, in one, special tools in another, setting, manufacturing delays, scrap, added time, would all have their separate accounts.

The departmental manager, in preparing his budget request, will obviously require to have information as to past performance and as to anticipated activities in the period for which he is budgeting. In practice it has been found satisfactory to supply him with these papers :—

(1) A schedule of anticipated production, indicating the productive labour involved in his department, and preferably broken down by months.

(2) A data sheet for each account on which he has spent money in the previous year, showing the actual amount spent in each of his divisions, and also, where applicable, throwing up the expense as a percentage of productive labour.

(3) A work sheet for each account on which he is required to enter his anticipated expenditure for the next year.

An extremely important feature is the establishment of " variable rates," which are inserted to take care of fluctuations in production after the budget has been set. However carefully the sales department have done their " crystal-gazing " there is almost certain to be some variation between the budgeted and actual production, and obviously a budget established on the basis of—say—1,000 units per month is not going to stand in the case of 800 or 1,200 units being actually produced. The term " variable " is used to describe that portion of the expense which can be expected to fluctuate directly with a rise or fall in productive labour. It will be clear that from a purely financial view-point the higher this degree of flexibility can be set the better. If sales volume drops then obviously it is financially desirable that expense shall drop as near as possible in the same ratio. At the same time all sorts of other considerations come into the picture—in the case of non-productive labour for instance, local circumstances and management policy with regard to " continuity of employment," etc., will considerably influence the variable rate. In some parts of the world where labour is decidedly more " fluid " than in this country it would be quite sound to budget some of the labour sections at a much higher variable rate than would be practical or ethically desirable here in Great Britain.

Some accounts, such as depreciation, rents and rates, are with us 100% whatever the production circumstances and we have to regard such items as completely non-variable. On the other hand, certain sections of expense can legitimately be considered 100% variable—for example, tools, lubricants, processing supplies and scrap.

The correct variable rate on any account may be anywhere between these two extremes and can only be determined by a careful study of all the relative circumstances. The variable rate is the keystone of budget control, but at the same time is the most difficult to assess. This piece of work is full of pitfalls—as an example take such an account as setting ; at first glance it could easily be thought that this should bear a fairly close relationship to productive labour, but in actual practice there may be perfectly sound reasons why setting costs should be in an inverse ratio to production—a drop in volume involving smaller batches and more frequent set-ups. All these points have to be considered in arriving at a workable percentage, and it may take years of experience before a satisfactory rate can be established.

The departmental budget request will, of course, give full details of the proposed expenditures, including names and wage-rates of non-productives, and reasons for any serious variations from previous standards. The next move is to bring together all the various requests and present to the management a complete picture of the whole plant. The budget committee then examine the total request, item by item, and the departmental head concerned will be present at the time of consideration of his department's request. He will be called upon to justify proposed increases and probably be read a homily as to why some of the things he wants to do can't be done. A certain " target " element may be introduced—we all expect to be better next year than last—and finally the budget is " approved " more or less to the satisfaction of everybody concerned. The departmental budget with each account marked up with the amount and variable rate decided upon, is returned to the departmental manager and becomes his financial Bible for the ensuing year.

Now, obviously a budget prepared on a yearly basis has got to allow for a degree of flexibility from month to month. Most of us have probably heard stories of the wonderful systems whereby somebody makes a budget of thousands of pounds in November, 1936, and at the end of 1937 finds that his actual expense and his budget agree within .00 something %, and, if we are sensible people, we don't believe them. Anyway, if it were true it would indicate either a wonderful fluke or an appalling degree of stagnation. In actual practice, right from the first day the budget operates, you will be making economies that put your budget too high, or agreeing to additional expenses (with good and sufficient reason) which will mean that you haven't enough money " in the bag." And so, we introduce a monthly expense forecast for each departmental manager. This forecast gives the theoretical budget expense for each account, worked up on the basis of the expected productive labour for the one month and written up or down according to

circumstances which have arisen since the yearly budget was prepared. In other words, the forecast gives figures which bring the budget right up-to-date, and ought to be capable of realisation. This is the document against which the actual expense is compared, and weekly comparisons are issued showing the trend as compared with the forecast.

Every item of expense, material requisition, day-work card, scrap ticket, etc., is logged against the appropriate account number and budget responsibility, and excesses over forecast are quickly and clearly thrown up. This in itself is a tremendous advantage, but obviously the full benefit of budgetary control is not going to be obtained unless prompt action is taken to bring the overrunning accounts into line.

The method employed will inevitably vary from account to account and from factory to factory, but there is one point in common to all accounts and to all factories, namely that the actual physical control must be carried out with the full co-operation of the man on the job—the charge-hand, foreman, or departmental manager. The proper function of the budget accountant is to keep the departmental manager aware of his financial position and probably, by reason of his knowledge of savings effected by certain methods in other departments, he may be in a position to make suggestions and recommendations, but in the final analysis the actual lining up of expense with budget is in the hands of the man who signs the requisitions and labour cards, etc.

Purely from an accountant's point of view it would be desirable that no requisition or expense work order were honoured until it had been O.K'd by the budget department, and I believe this procedure is attempted in some factories. We have never tried it ourselves and I should imagine that in any large-sized plant it would involve tremendous difficulties and delays.

There are, however, some categories of expense which can be quite conveniently checked by the budget control department in advance. For instance, non-productive personnel can be covered by having the labour requisitions routed via the budget office where they are marked up to show whether the proposed addition are, or are not, financially sanctioned. This ensures that the official who finally approves the addition is, at least, aware of the financial consequences and he should require a really good reason before giving his O.K. to something which will cause an overrun. In the same way, the transfer of a productive man to a non-productive job ought to receive the blessing of the budget department before being made effective.

Certain routine non-productive jobs lend themselves fairly easily to being budgeted at so many man-hours per week—such items as Spray Booth cleaning, truck maintenance, machine oiling, etc.

The hours approved for this type of operation should be advised to the foreman concerned and if it is proposed to make additions as the year progresses the budget department should be informed so that the item can be marked up in the budget with the " alibi " for present overruns, and for attention in compiling future budgets.

As regards tool and die setting, it should be possible to establish fairly reliable ratios to productive labour for the various divisions and weekly checks set up. Incidentally, although for reasons I have already mentioned, there can arise day-to-day circumstances which play havoc with your short-term ratio on this account, we have found that in actual practice surprisingly close comparisons can be achieved over a period such as a year. A memo of the actual setting ratio can be issued week by week to the departments concerned, and if a simple chart of these ratios is kept in the shop office an obvious warning is given as soon as anything begins to go " sour."

The added time you pay for the privilege of working men overtime can be a very expensive item for which the firm gets precisely nothing back in the way of concrete work, and so it must be controlled as rigorously as possible. Probably the best method of dealing with this one is to require a daily statement from each division as to what overtime is proposed and why. This document ought to require the approval of the management and does not strictly come within the scope of budget control, although that department can conveniently check that the approved figures are not exceeded and should certainly have a responsibility to investigate the reasons for these expenditures, and in some cases may be able to make suggestions to obviate future charges.

Inspection in any big production plant will represent a pretty large slice of expense—in my knowledge of the motor industry there are cases of from 4 to 11% of productive labour. Clearly an item of this magnitude is going to justify a good deal of control work, and equally clearly the permitted standards are going to vary widely from department to department. Where it may be quite reasonable to pay, say 10% of operating times on some critical operations with particularly fine limits, it may be just as sound to pin it down to, say 4%, in the next department.

The Budget should therefore be built up departmentally and the foreman inspector of each department would be given the responsibility of seeing that his ratios to productive labour were not exceeded. The number of inspectors permitted in each department would be governed by the approved ratio and weekly checks made by analysis of the inspection payroll. In periods of short time being worked by the operators this weekly check should specifically cover that the inspection hours are reduced pro rata. This last point, incidentally, does not apply to inspection alone. One of the most persistent

sources of budget overrun is the lack of agreement between hours worked by productives and non-productives at a time of decreased production schedules. Unless this point is watched very carefully you can easily find yourself in a position where your productive men are working short time, but your labourers, material handlers, inspectors, maintenance men, etc., are all consistently with you for a full week.

Maintenance labour in a sizeable works is, frankly, the very devil to control. There are a number of regular functions to which I have already referred which can be established on a weekly or monthly basis and covered by a standing order, the costs of which are regularly scrutinised. You can make a set-up whereby no job likely to occupy more than, say, ten hours, is started until sanctioned by management-approved work order, which will carry a labour and material estimate. But you will always have to make exceptions in the numerous cases of breakdowns and similar happenings which involve the job being dealt with immediately and on which it is difficult, if not impossible, to estimate in advance.

The plant department men may quite legitimately be clocked on to any one of a dozen or so accounts which my system visualises, such as buildings maintenance, equipment maintenance, furniture and fixtures maintenance, rearrangements, etc., and, as far as I can see, the only effective control on maintenance must be the number of plant men on the payroll and the hours they work, and incidentally I should imagine it would be a very poor maintenance foreman who couldn't put up an unshakeable case for twice as many men as he has got at any particular time

When we come to consider non-productive supplies we are on much firmer ground. It should be possible to set up standard issues per job or per £100-worth of productive labour on a large proportion of items in the category—the amount of petrol permitted per engine tested, number of sanding discs per body produced, quantity of cleaning rag per £100 productive labour, gloves and other protective clothing—all this type of thing can be fairly easily lined up with productive labour. The actual control can be achieved in several ways. You can issue " sanctions " to the storekeeper (say weekly) based on the scheduled production and he will honour the foremen's requisitions up to the limits indicated, and no more. If for any reason it is considered absolutely essential to exceed the sanctions, the requisition will need to be countersigned higher up the organisation and will be the subject of a special inquiry by the budget department. Another method is for the amount of money available to be indicated to the departmental manager, who will in turn break this down amongst his various foremen who, by means of daily record sheets (written up from copies of the requisitions) are constantly aware of their position as compared with budget.

This, of course, involves the foreman being kept aware of the price of everything he uses and I might interrupt myself to state that I consider this extremely desirable. For some reason I have never been able to understand it has been the traditional practice in large numbers of firms to regard this sort of information as " semi-confidential " and I consider this to be entirely wrong. Everybody who is in the position of spending the firm's money should, as far as ever possible, be aware of the financial consequences of what he is doing. When we first opened up on this a few years back the effect was a number of suggestions for substitutions, which resulted in some very useful economies. The foremen had quite a shock when they became aware for the first time of the prices of some of the items they had been regularly using for years, and as a result of their own suggestions, we were able to employ cheaper, and equally satisfactory, alternatives.

A quite important point in this " supplies " section is the proper control of what might otherwise pass as " unconsidered trifles." I remember that in our early days of budget control we were able to bring about a very useful little saving by concentrating for a time on rag issues. This uninspiring commodity only costs a few coppers per lb., but in our factory runs away with something like £960 per year overall. In expense control the proverbial advice about taking care of the pence is extremely sound—although unfortunately you can't accept the latter portion of the proverb without a good deal of reserve !

For reasons which you probably know better than I, it is difficult to take a hard and fast " so much per job " basis with tools, although I have recently come across a plant where at least the main lines of standard tools are issued only on a production schedule basis and detailed records are maintained of the number of pieces produced against each tool or re-grind. Without going quite as far as this we have found it possible to determine fairly reliable ratios on the " cost per £100 productive labour " basis for the different producing groups. Regular, say monthly, checks against this formula can certainly be very useful in throwing the spotlight on excess usages or manufacturing difficulties which might otherwise be hidden up for a long time. Only recently we had a case in the factory where this monthly analysis brought to light the fact that the tooling on a particular new part was running excessive and the figures we were able to throw up were such an eye-opener to the engineering department that they sat down and re-designed the part.

The cost of the initial equipment of special tools, jigs, etc., for a new model will be capitalised under the original project and written off direct at so much per unit produced over the anticipated life of the model outside of expense control routine. Replacements of this type of equipment, however, will figure in our month-to-month

expenses and can be controlled by the issue of priced work orders to the tool room or jig shop, who will pass the completed tool through the tool stores to be issued against departmental requisition in the same way as the standard tools. They will remain on inventory until such time as requisitioned by the shop foreman, who is thereby charged only with items over which he has direct control.

When you come to gas, water, and electricity, your tie-up with productive labour is less direct, but a weekly reading of your meters compared with your budget will put you immediately on the track of excess consumptions, and provided your meters are intelligently placed your field of investigation can be narrowed down. In the case of process gas it should be possible to maintain a reasonably close relationship with productive labour, and the weekly comparison will be of assistance to the official concerned in arranging his furnace hours.

In the case of scrap, which costs most of us a lot of money, it may be surprising to learn that this is an account which lends itself very easily to the " per £100 productive labour " control basis. On the face of things one might imagine that scrap comes almost under the " act of God " category—it seemingly arises from somebody doing something they ought not to do, or failing to do something they ought to do. And yet in actual practice the legitimate ratio of scrap to productive labour in any productive group can be assessed very closely after a few months' experience. Which means that the budget control system can be very useful indeed in this connection. Having established your ratios, it shows the red light immediately anything begins to go wrong, everybody concerned becomes painfully aware that things are not as they should be, and steps can be taken to deal with the trouble. Your cold financial statistics will, of course, be supported by a daily return of scrap tickets, and it is only a matter of quick analysis to see where the trouble lies.

Material may be scrapped or re-worked after it has left the divisions responsible and it is, therefore, desirable that a copy of the scrap or rework tag shall be routed to the department being charged so that the foreman of that department is aware of his department's shortcomings and can pick up the trouble before it reaches the " epidemic " stage.

I might here make the general point that as far as ever possible a departmental head must be kept aware of every charge which is being debited against him. The bulk of these charges will, of course, consist of his own requisitions or job cards, but there are bound to be some debits which arise in other departments, for which he has to be held financially responsible, and in these cases the set-up should ensure that he is kept immediately aware of such charges. A case in point is where a delay occurs in Department B. as a result

of non-availability of material from Department A., who may be behind schedule on some part or other. The operators in Department B. will be entitled to some allowance for their lost time and Department A's budget will be called upon to pay for it. In such cases we have instituted a procedure whereby the allowance will not be honoured until initialled by Department A, which serves the double purpose of checking the time charged and notifying the offending department that a charge is on its way.

In general we should aim at localising every item of expense to the greatest possible degree. In any large sized plant we can't avoid having a certain amount—and probably a very large amount—of expenditure of a general character, ranging from the Managing Director's salary to the cost of maintaining inter-department conveyors, which we can't pin down to any one particular division and which we have got to apply on a percentage basis to the burden rate of every department. It therefore becomes necessary to departmentalise the greatest possible amount of operating expense, even if it seems here and there to throw up something that might look like a financial injustice. A foreman may not be able to prevent a machine breakdown, but the loss involved is very definitely part of the cost of running his department and should figure in the expense and burden rate of his section. " Everybody's business is nobody's business " and we should aim at attaching as much of our expense as possible to individual responsibility. At the same time it is necessary to keep a sense of proportion about this divisional allocation of expense—unless you watch it you can easily have a situation where highly-paid people are wasting valuable time arguing and writing inter-departmental notes about the responsibility for a few shillings, which the firm has got to pay anyway. It is quite a desirable thing for a departmental manager to be jealous of his good budget position, but this is not much use if it is maintained at the expense of other departments, or at the cost of inter-departmental friction.

So far I have confined my examples to the operating side of the business, but the same general principles apply to the control of commercial and administration expense. Generally speaking these accounts should be less difficult to control effectively in so far as such a high proportion of the money involved is likely to be related to staff personnel and similar items not likely to be affected by minor fluctuations in production. By this I don't mean to suggest that we should accept the clerical, engineering, spares, planning, etc., payrolls as completely non-variable, but the probability is that in practice the variability of these accounts will be more related to the type of production (number of models, etc.), rather than to volume. My suggestion here would be for a relatively low variable rate as a target on the grounds that in times of increasing volume

(with presumably increasing profits) we might be prepared to spread ourselves a bit on this type of expense, while on the other hand when things were not so good we should run into a " tight " budget situation which ought to ensure a keener scrutiny of the charges and particularly of proposed additional charges.

The control routine on this type of account is quite simple, the names and salary rates of the personnel are listed in the original budget and this list is maintained up-to-date by the budget department being advised weekly of alterations, by the staff payrolls department.

I have dealt with these few accounts more or less at random without any pretence of covering the whole field, but I hope I have been able to convey some idea of how the scheme works.

An essential complement to any effective budget control system is some method of quickly pricing and tabulating the various pieces of paper which go to build up the charge against each department, which, in any sizeable organisation probably means a mechanical tabulator of the Hollerith or Powers type. The essence of control is to get your facts quickly—in some sections your budget control is almost bound to have a certain element of " locking the stable after the horse is stolen " about it and in these cases the job must be to ensure that only one horse gets away. I have known only a very few cases where an overrun cannot be amply justified by the department concerned, but in most instances the very fact that the item has been queried and explanations called for is sufficient to ensure that the same excess will not recur. In the same way, the very existence of a budget control department and the knowledge that overruns will be quickly detected does in itself play a large psychological part in preventing such overruns ever occurring.

This leads me to the point that the budget control department ought not to begin and end as a piece of accounting machinery. Correctly constituted it should function as a sort of permanent economy committee. It should not, of course, encroach on the technical departments, but outside of this it should be continuously on the job of trying to find ways and means of saving money. In conjunction with the buying department it will be constantly on the look-out for cheaper alternatives for supplies, and will keep itself informed of new developments and systems which may be worthy of investigation and trial. It will review the non-productive labour personnel and make suggestions for revisions of shift systems, etc.

At the same time I should hate to have it on my conscience that I had persuaded anybody that by putting in a piece of office organisation with a few bright young men and labelling it " Budget Control Department " you have solved the problem. It doesn't work that way at all. To get anything like the full benefit of budget control

involves the complete understanding and co-operation of the whole organisation, and I cannot stress too much the importance of getting the active interest of the lower ranks of supervision and administration. The aim should be to develop a "budget-conscience" throughout the organisation and the measure of your success in expense control will largely depend on how far you succeed in doing this. It does seem to me that there is some room for criticism in the general procedure in creating foremen, etc. We are rather apt to take a man who is a particularly good operator and who appears to have possibilities as a supervisor, and make him a foreman, thereby putting him in the position of spending hundreds, or maybe thousands, of pounds of the firm's good money every year, without doing very much, or even anything at all, about his education in the financial side of the business.

Properly encouraged the people lower down the scale can probably save you a lot more money than the most elaborate office systems. In point of fact one of our most successful money-savers has been the setting up of a simple form of manufacturing cost study, on which we invite anybody, including the man "on the clock" to put forward suggestions for economy in any direction. In this the budget department acts only as a sort of clearing-house and follow-up department—the idea comes from people actually on the job—but the result has been the saving of thousands of pounds over the last few years.

I want to conclude with a recognition of the fact that this paper only deals very superficially with this subject and I know you will appreciate that the methods employed must vary considerably between one plant and other. I hope that I have been able to give you some idea of the general principles. There is nothing mysterious or highly involved in budget control. It is purely the application of common-sense principles to the question of expense, and falls into the general scheme of things in a rationalised plant in precisely the same way as production planning and time study.

Recognising that in most large-scale factories now the amount of money spent on expense far exceeds the cost of productive labour, and also recognising that this trend is being constantly accelerated by technical and scientific developments, I think we can agree that the executive who fails to take advantage of some effects system of expense control is unnecessarily handicapping himself in the business race.

## Discussion, Nottingham Section

MR. H. J. GIBBONS (Section President, who was in the Chair): I assume that the title "How to keep over-heads within bounds" implies that by means of these constant references to budget control you can see how they vary from time to time, but it seems to me also that with your constant references back to the foreman, you must first of all turn your foreman into a financial genius, as against his technical capacity. I quite appreciate that in a highly organised concern the foreman can be that, but in many industries it is still the practice to appoint a foreman from amongst the technical workers—very often with no knowledge of finance. Do you think that budget control should be prepared by the finance side or by what is known to-day as the cost accountant? There is rather a difference of opinion between the finance accountant and the cost accountant. I rather disagree with you with regard to overtime, because if you can get a larger output out of the same capital charge, you have reduced the capital charge. I know the question of maintenance comes in but you have also to consider the question of obsolescence, and although the machine will not wear out, it becomes obsolete. If you can use it more in a certain number of hours the overtime charge in many industries is not so important as the capital charge.

MR. THEODORSON: First of all, the question with regard to the foreman. Throughout the paper I tried to make the point that the success or otherwise of budget control will ultimately depend on how far you are able to sell the idea to the man who spends the money, and that man in a very large number of cases is the foreman. I agree with you that you cannot expect to turn into a financial genius a man who has been brought up in a workshop, but I do suggest that we have got to get somewhere half way between that financial genius and what we have got in a large number of firms to-day, where a man is put in the position of spending money and is not given the prices of the stuff he uses and is not given any encouragement to take an interest in the financial side of the business. It as well worth while spending quite a time in at least getting into his mind the elements of finance control.

With regard to the preparation of the budget, whether by the cost accountant or by other people, in my paper I tried to make my point that we try to get everybody who is going to handle that budget interested in it from the beginning. The essential thing is to have the budget prepared by the man you are going to look to as responsible for looking after it. I can get that man to make the

budget himself—I may be able to lead him in certain directions—but I have left him with the impression that he has made that budget, and that is a very important point. I say to that man: "Here is £10,000 for you to spend, no more and no less," and if that man has built up his own budget on the £10,000 his psychological control of it is going to be infinitely better than if it is forced on him from another department.

I am sorry if I gave any wrong impression on the question of overtime. I would agree with you with regard to the necessity of utilising plant—which in these days rapidly becomes obsolescent—to its absolute capacity and I would never object to night shifts. I think in general it is true to say that if a plant sets down and budgets to work ten or twelve hours a day per man, it is wrong. If a man comes to work in the morning and knows he is going to work ten hours instead of his normal eight, automatically his pace is slower. Spasmodic overtime according to your sales demands—yes, by all means but as a matter of general principle I suggest that overtime is wrong. I was more concerned with the financial side of it—when a man works a couple of hours overtime and claims two and a half hours for that overwork, you get half an hour which is a dead charge and for which you get precisely nothing.

MR. VOCE: Foremanship is a very big question. To-day we are in a position where we have lost the proper apprentice and he has not had his training, and I must say that the picking of a foreman is one of the biggest questions we have got in the engineering trade.

MR. WOZENCROFT: The speaker pointed out how important it was for the foreman to know the cost of the materials, but is he aware how difficult this is, owing to the water-tight departments which exist in most organisations?

MR. THEODORSON: The trend in industry is inevitably towards that and you are bound to get it. The whole idea of the foreman having no concern as to what his department costs to run is absolute nonsense, and you can never stress that too much. You must give the foreman all the information he wants, everything he wants to know must be in his hands. We are probably talking of two different types of foreman. The foreman you have either in your tool room or your die shop will obviously be a different animal to the foreman you have looking after a squad of say 60 or 100 men who are on a line production basis, and you have got to recognise that point, but you can still take the trouble to educate both those men to a certain extent along the lines of expense consciousness.

MR. JOHNSTONE: I should like to ask, if it is not giving too much information out, the number of people that are employed in your budget control scheme in proportion to the number of men you employ, because in a smaller works I am always afraid of these checks

costing far too much, and they can run away with you if you are not careful.

MR. THEODORSON: Budget control at Vauxhall Motors consists of myself first, and I have two assistants and a typist, and then we have a separate budget control for the engineering department consisting of one accountant, and for the supply department consisting of one accountant. Where budget control finishes and ordinary cost accounting begins is only determined by different factories. The actual tabulation of figures is done outside my department. In general, it does not cost a tremendous amount of money to us. The fact that it may pay a large scale production firm to spend quite a few thousand pounds a year does not mean that it would pay a small firm, and the cost of the checks would be greater than the amount of money those checks might save. Obviously, if you can spend £5,000 in a fairly large factory and save £20,000 you are doing right, and if you can spend £5 in a small jobbing shop and save £10 you are still doing right.

MR. LAWSON: May I ask Mr. Theodorson whether the budget control department is vested with any authority or does it act in an advisory capacity only?

MR. THEODORSON: It is not very easy to answer that. You cannot draw a clean-cut line. The budget control department has to a large extent the authority it can develop for itself. It must get a good reputation with the people who have got to work under that control. On the other hand, if you have a narrow-minded type of accountant in charge, his control can be absolutely limited as to what the managing director says he can do. The control is largely how he builds up his job, and it is essential that he should have a degree of final authority.

MR. PUGH: Regarding the number of people that run a budgets department, from my own experience I know of one particular firm employing about 5,000 people—they have a budgets officer, one fully qualified plant engineer who investigates all expenditure. two clerks and one typist—and they make a very good job of it. I should like to ask one question—what are your views regarding giving foremen or shop superintendents a certain proportion of the savings effected by the budget? Shall we say, if he is allowed £100 and only spends £80, whether the foreman should have a certain percentage of that saving as an extra incentive?

MR. THEODORSON: That also is not an easy one to answer. Some firms do that. As a matter of fact, we regard it as part of the foreman's job for which he is paid, to look after the finances of the firm. The scheme you suggest would possibly lay itself open to

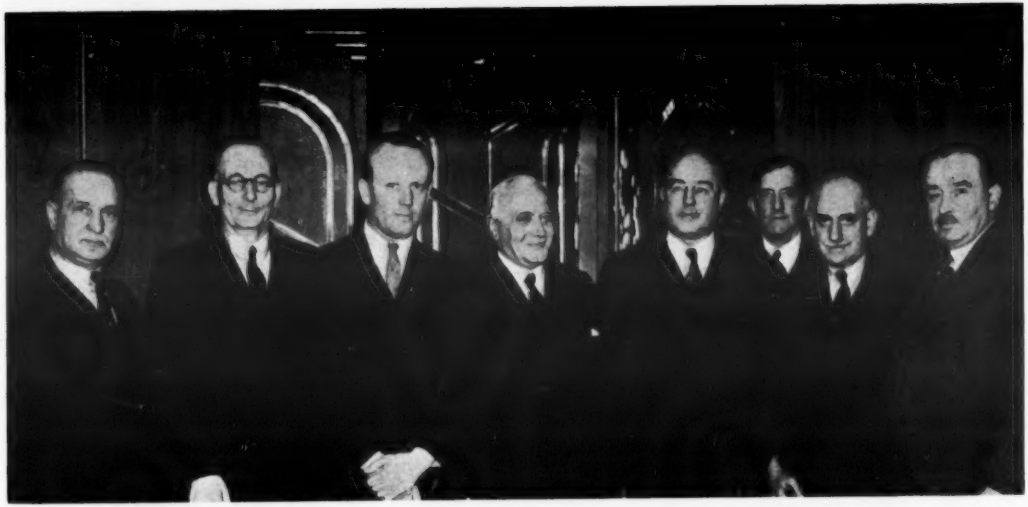
abuse. You know very well that a foreman can save money by good methods and by methods which may ultimately cost the firm money. We have not considered from the management point of view any kind of incentive bonus on savings on budget. If you do that you ought to be in a position to debit the man with over-runs, and there again you are doing the man a tremendous injustice. You are bound to have a certain amount of over-runs, and you would be unfairly penalising the man who could not help overspending that amount of money.

MR. HOAD: I would like to say how much I have appreciated the easy way in which the lecturer deals with the question of controlling budgets. It seems to me that he must plough a fairly easy furrow. He knows just what everybody is going to spend, he knows what they have spent, and he just takes one from the other and the net result is that he knows just which push he has got to put his finger on, and the thing works at the other end. At the time of the Motor Show we read that Vauxhall have just netted orders for £250,000, that Morris have also landed 180,000 cars and that the Ford people have got their next twelve months output already bought before they leave the Show, therefore our lecturer starts with a definite and known quantity. He knows before he begins on January 1 just where he is going to be on December 31. All this, of course, makes the thing very much easier, but how would the situation apply if your contracts are not there before the Show starts and that you do not know on January 1 whether you are going to make two engines or whether you are going to make 22 on £12,000? It makes a lot of difference, doesn't it?

MR. THEODORSON: In establishing your budget you have got to establish it on a basis that will allow for these variations, and I tried to emphasise the necessity for this variable rate as we term it. All I can do is to lay down certain general principles. If you accept those general principles—and experience has shown them to be, generally speaking, right—you can apply them to almost any industry, some much easier than others.

MR. GIBBONS: I am sure you would wish me on your behalf to thank Mr. Theordorson. He has certainly put a good deal of "vim" into his paper, and it has been carried on in a very happy vein.

MR. C. HOLLYOAK: I should be delighted to second the vote of thanks. It has been a very good meeting and I am sure that everyone, like myself, has thoroughly enjoyed it.



**MEETING OF THE COUNCIL, NOTTINGHAM, MARCH 18, 1939**

*Left to right:* **J. D. Scaife, C. Hollyoak, Lord Sempill, H. J. Gibbons, J. G. Young, R. Hazleton, T. Fraser, J. H. Bingham.**

# SPOT WELDING

*Paper presented to the Institution, London Section, by C. W. Leng, A.M.I.P.E., F.R.S.A., with report of Discussion, London Section.*

## Introduction.

A few years' ago a realisation of the comparatively unsatisfactory conditions of the spot welding process led to a careful study of the subject. The fundamental principles underlying it were investigated and the knowledge gained applied to practical use, and an organisation was established which yelded results of a high degree of quality and uniformity. This paper is presented in order to record something of the work that has been done and particularly to emphasise that the results achieved were not by any " hit and miss " methods but were directly built up on the foundation of theoretical investigation. This fact is emphasised because of the importance of a knowledge of the principles underlying the process in order that intelligent control may be exercised, and because it has been learned how essential a most rigorous intelligent control is. The basic principles are deeply rooted in the physical structure of matter and the manner in which that structure is affected by the passage of a very large electric current in a very short period of time, whilst it is being gripped under a very high pressure. These matters will be briefly discussed and will be followed up by a consideration of the practical issues arising from them in their relationship to production.

A spot weld is a small lens shaped weld joining together sheets of metal superposed on each other. It is made by the heating effect of an electric current having passed through the metals. The current is carried to the weld area by means of a pair of electrodes which make contact with the material to be welded over a small area of the same order of size as the weld made. The electrodes press hard on to the work in order to make a sure contact both electrically and mechanically. If the nature of the path of the current in the vicinity of the weld is considered together with the effects of a current passing through it, a picture may be obtained of what takes place when a weld is made, and such a picture is a useful mental setting in which to measure and resolve future problems. That part of the path under consideration consists of two electrodes and

*16 January, 1939*

two pieces of metal to weld—four pieces in all, but there are some other less tangible components and these are three surface contacts—consisting of two between electrodes and work and one between the two pieces of work.

## Nature of Surfaces.

These surfaces are variables whose nature has been determined by a number of circumstances : (1) The nature of the material itself. (2) The method by which that material was produced (either hot or cold working, pickling, annealing, etc.) (3) The substances with which it has come in contact since its manufacture. (Atmosphere, moisture, chemicals, abrasives, knocks and blows, etc.).
(4) The length of time it has been exposed to these conditions.

The analogy between the ultimate metal surface and the surface of a portion of the earth is not too far fetched.

Take a region with a substratum of clay. The surface usually consists of 6 in. or 8 in. of soil covered with grass or some form of vegetation. The soil is modified clay, modified by the atmosphere, moisture, frost and perhaps even the plough. The vegetation is a further modification due to more elaborate chemical and physical actions.

On the metal, oxides are formed by exposure under changing temperature and moisture conditions, and the analogy to vegetation is sometimes found in effects of corrosive chemicals on the surface. The physical properties of the surface, therefore, will be entirely different from those of the underlying material and will vary in proportion to the degree of modification. The components of that part of the welding circuit we are considering all possess, then, their own physical characteristics, each of which has its influence on spot welding.

These characteristics are : (1) Electrical conductivity. (2) Specific heat. (3) Density. (4) Welding temperature. (5) Thermal conductivity.

## Electrical Conductivity.

Electrical conductivity is a fundamental property of metals possessed by all of them in a greater or lesser degree. In making an attempt to graphically picture the phenomena involved, it may be said that the atoms in a metal are arranged in an orderly fashion and are held together because their valency electrons are shared by the community. The degree of sharing or freedom of movement possessed by the valency electrons is the measure of the electrical conductivity of the metal.

When an electrical pressure is applied across a piece of metal, the free electrons all move in the direction of the pressure and the magnitude of the movement (current) is determined by the degree of

pressure and the freedom of movement of the electrons (conductivity). If electron freedom is less in the case of one metal than another, then more electrical pressure will be required to cause the same magnitude of current to flow; in fact, the pressure, current and conductivity or its resistance are related by the well-known law $E = IR$. Therefore, with any given degree of resistance, the amount of electrical energy (W) required to overcome it will be the product of the pressure (E) and the current I

$$W = EI = I^2R$$

This energy overcomes the resistance by causing the snugly held atoms to be disturbed from their comparative repose. They vibrate about their moorings with considerable excitement due to the energy they have absorbed from the passage of the current. *Specific heat, temperature.*—The amount of energy that is required to cause a definite degree of vibration is known as the specific heat of the metal and the temperature is the measure of that degree of vibration. Now when the excitement has become so intense that the atoms break entirely away from their moorings, their disciplined ranks are broken and the structure collapses into the liquid state.

*Density.*—The amount of energy required to raise the temperature a given amount is also governed by the density, or the mass of metal in any given volume.

*Thermal conductivity.*—Further it is governed by the time during which the current is flowing, because the excited atoms resent the disturbance forced on them and pass it on to their neighbours who feeling equally resentful pass it on still further. This conductivity of heat takes place at a fairly high rate in some metals so that it is possible for the heat to be conducted away as rapidly as it is put in.

*Welding temperature.*—Now in spot welding the temperature to which it is necessary to raise two pieces of metal under pressure in order to weld them is known as the welding temperature. It is determined by certain physical characteristics of the metal, the pressure and the time for which it is applied. It varies from the melting point in some metals to comparatively low temperatures in others. For example, aluminium needs to be fused because it does not become plastic before melting. Steel is welded at temperature considerably below its fusion point because being plastic it can be forge-welded. Silver has recently been welded at a temperature as low as 200°C. with a pressure of 45,000 lb. per sq. in. applied for sixteen hours.

*Energy to make a weld.*—Now from the foregoing an expression can be obtained which defines the energy consumed in making a spot weld.

The actual amount of heat energy required to weld two sheets of metal, assuming pressure conditions are right will be—

$$B = I^2R = 4.2\ \theta HDV.$$

where $\theta$ = welding temperature.
$H$ = Specific heat.
$D$ = Density.
$V$ = Volume of weld.
4.2 = Factor for converting watts to calories.

When this factor is considered in relation to the time taken to make the weld, the thermal conductivity of the material and the electrodes must also be considered. And the expression for any given temperature $\theta°$ at the weld and at any given time $t$ in seconds becomes

$$B = B_o + B_m + B_e + B_c$$

where $B$ = total heat supplied in calories.
$B_o$ = ,, absorbed in weld.
$B_m$ = ,, conducted from material.
$B_e$ = ,, conducted through electrodes.
$B_c$ = ,, developed at electrode contacts.

$B_m$ consists of two components —

1—heat conducted to electrodes.
2—heat conducted away radially in the material.

The heat conducted away is expressed as follows :—

$$B_e + B_m = \frac{KaT\ (\theta_1 - \theta_2)_e}{l} + \frac{KaT\ (\theta_1 - \theta_2)_m}{l}$$

where $K$ = thermal conductivity.
$a$ = the cross sectional area of the conducting path.
$T$ = time in seconds
$l$ = length of conducting path.
$\theta_1$ = temperature at origin of l.
$\theta_2$ = ,, end of l.

The full expression is rather cumbersome and the second part of $B_m$ is not easy to determine, but making allowances for all these things if one has the patience to make the necessary calculation,

much enlightening information becomes available. Consider now the case where two copper electrodes are being used to weld two flat discs of fairly thin sheet mild steel.

The electrical conductivity of the path will then be made up as follows : The conductivity of the copper electrodes will be represented by 100 and that of the iron discs roughly 20. Now it is impossible to assess the value of the conductivity of the contact surfaces. It is determined by the conductivity of the contacting surfaces themselves and the amount of molecular contact they make. As has been shown, the surface conductivity of a metal is rarely the same as that of the body of the material because its physical architecture is usually quite different and also there are frequently impurities in it. The amount of actual contact taking place will be determined by the " profilometry " of the two surfaces and this will be much influenced by the pressure. For this argument let us assume that the surface conductivity is the same as that of the metal itself but that the surface contact is one half the area of the tips.

Taking the reciprocal values of conductivity we get the resistivity and—

$$R_c = \frac{R_{s1} + R_{s2}}{2\,ac}$$

Where $R_c$ = contact resistance ;
$R_{s1}$ and $R_{s2}$ = surface resistance of contacting metals ;
ac = area of contact.

This is modified by the pressure with which the surfaces contact. The area of contact will increase with increase of pressure according to some power of the pressure. Therefore, the resistance will decrease by the same law—

$$R_c \propto \frac{1}{px}$$

Then the resistance between the tips and the metal will be—

$$R_c = 6$$

and that between the metals will be—

$$R_c = 10$$

The relative resistances now become

| | |
|---|---|
| Electrodes... ... ... ... ... | R = 1 |
| Discs ... ... ... ... ... | = 5 |
| Electrode disc contact ... ... ... | = 6 |
| Disc to disc contact ... ... ... | =10 |

Now the amount of heat produced by a current is the product of the square of the current and the resistance $I^2R$.

It will be seen, therefore, in this case that with any given current the heat energy produced at the disc contact is greater than at any other part of the path. Now as the specific heat of copper and M.S. are approximately the same but the resistances of each bear the ratio of 1—5, any given current will raise the temperature of equal volumes of these two metals in the ratio of 1 to 5 and when the welding temperature is reached in the M.S. the electrode would normally be comparatively cool or only about one-fifth the temperature of the weld, but there is the question of thermal conductivity which is of the same order of comparative value as the electrical conductivity and, therefore, in any given time about five times as much heat will be carried away by the copper electrodes as by the iron discs. Therefore, the electrode tip temperature will be increased by heat flowing out of the weld. This is a favourable condition which when coupled with well designed water-cooled electrodes enables long life to be obtained from them. Let us pursue these thoughts a little further.

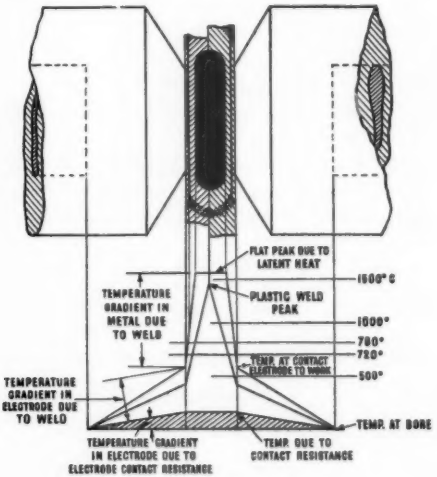

FLAT PEAK DUE TO LATENT HEAT
1500° C
TEMPERATURE GRADIENT IN METAL DUE TO WELD
PLASTIC WELD PEAK
1000°
780°
720°
TEMP. AT CONTACT ELECTRODE TO WORK
500°
TEMPERATURE GRADIENT IN ELECTRODE DUE TO WELD
TEMP. AT BORE
TEMPERATURE GRADIENT IN ELECTRODE DUE TO ELECTRODE CONTACT RESISTANCE
TEMP. DUE TO CONTACT RESISTANCE

Fig. 1.

## Thermal Diagram of Weld.

In the diagram is shown schematically the two pieces of M.S. between the electrodes. The weld is shown by the characteristic lens shaped button and the water bores are shown dotted in the

electrodes. Above is a thermal diagram calculated from the expression we have just mentioned and whilst it does not purport to have taken every factor into consideration it gives a very good picture of thermal distribution at the instant of current cut off. The flat top shows a level temperature at fusion point due to the latent heat of fusion of the metal. Falling through a steep gradient to the electrodes, the temperature passes down to some 600° at the surface. From its entry into the electrodes it drops to the temperature of the water in the cooling bore. The shaded portion at the bottom represents the effect on the thermal condition due to the electrode to metal contact resistance. Tracing upwards on the thermal gradient curve from the electrode contact to the weld, it will be observed that at some point up the curve the temperatures 720° and 780° are passed through. Now in 0.4% carbon steel these temperatures are the upper and lower critical limits. Above these temperatures the steel is completely in the austenitic condition. Then right at the top where it arrives at the fusion temperature, a margin will exist where the metal is partially molten.

If in the diagram these temperature ranges are projected upwards they show as bands around the weld and five distinct zones are visible: (1) The fused weld ; (2) the partially fused zone ; (3) the zones of metal that has been austenitic ; (4) the zones of metal that was in between the critical temperatures ; (5) the unmodified zone.

Now in a suitably etched micrograph all five zones are distinctly visible ; the local heat treatment having permanently modified the physical structure of the metal. The value of this kind of study is manifest when applying spot welding to Duralumin, stainless steel and other special alloys. Chiefly because it is necessary in these cases to prevent the outer metal from attaining temperature that will modify the structure, because their corrosion resistant qualities will be impaired by such a modification.

### Instantaneous Cut-in Voltage.

Another instance of the use of the equation was to determine the effect of the instantaneous cut-in voltage on the weld. Aluminium was taken as the metal and the first curve was based on results of a theoretical case where the welding current cut-in on the node of an A.C. cycle and the weld was complete in one-quarter cycle (Fig. 2). The conditions were calculated for each one-thousandth part of second during the welding period. No account was taken of the impedance of the secondary circuit in this case, because of its great variation under different circumstances, and the fact that the general teaching of the results would be very little different.

The curve shows the steady rise of temperature to the welding point following close after the energy input.

Now under the same conditions calulations were made assuming the energy input commences at the peak of a wave, in this case the energy value decreases as the current value falls for the first quarter

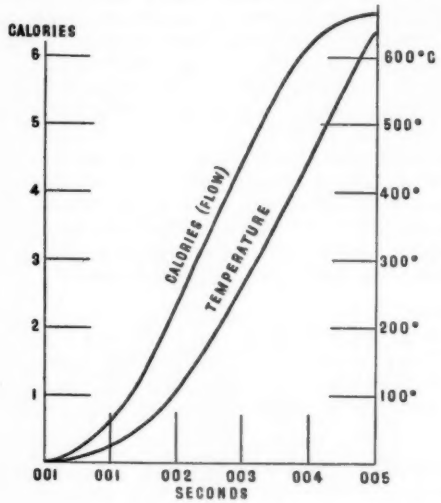



Fig. 2

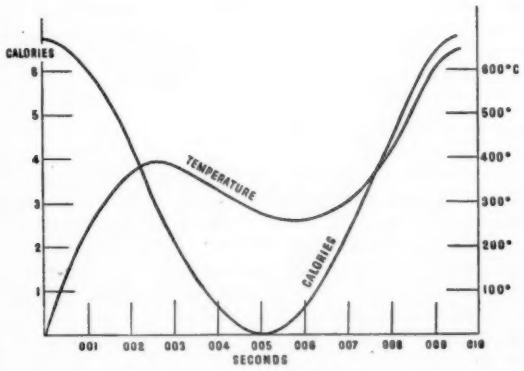



Fig. 3

cycle and then rises again to the original value at the end of half-cycle. (Fig. 3). The temperature curve rises rapidly at first, and then begins to weaken off and then fall when it reaches a point where the energy input is lower than the losses by conduction. As the input increases on the next quarter-cycle and eventually exceeds the losses the temperature again begins to rise, but in this case a complete half-cycle has elapsed before the weld is made. It has taken 100% longer to make this weld than the previous one. The value of this study is to show that very fast welds must be timed to cut-in relative to the instantaneous voltage of the A.C. cycle, and this applies to all cases of high conductivity metals being welded in quicker time than about five cycles.

A realisation of the significance of these happenings—the extremely short times during which so many things happen, the critical condition of pressure and current during these very short time intervals emphasises upon us the necessity for a very rigid control over every factor that could in any way affect the results.

The necessary factors are good materials, good design of parts, good equipment, good control.

These four main divisions indeed become the basis on which all good spot welding is made whether on the highly critical alloys of steel and aluminium, on ordinary mild steel and iron, or aluminium and its less critical alloys with metalloids such as silicon.

Let us consider some points under each of these headings

*Good material. Specification.*—The quality of a material must be determined by the work it has to do, and the processes through which it has to pass. For example, such a mild steel as is used for furniture or motor car body work is known to have good qualifi-qualifications of weldability. In view of this it is necessary for the welding engineer to know as much about this particular steel as possible. This information needs to be tabulated in the form of a specification in order that repeat orders may be executed in the same quality. This emphasises the need for purchasing from reliable manufacturers, for thorough raw material inspection, and for the purchaser reserving the right to reject material not conforming to the standard laid down in the specification.

The most important factors affecting spot welding are as follows :

(1) Chemical composition which can be checked by analysis.

(2) Heat treatment, mechanical working and pickling which aren ot easy to specify and can only be checked by the results. Hence the need for mechanical tests, for such qualities as hardness, tensile strength, elongation, etc.

(3) Surface finish which as far as spot welding is concerned only needs a careful visual inspection.

(4) Thickness limits which need the usual micrometer inspection.

The best test of all is an actual welding test on samples from fresh supplies. This may be carried out very simply, or in the most elaborate laboratory manner. A very simple manner is to reserve for use as a standard a small stock of material that has given good results, in order to make comparative tests with the new consignments. Then pieces of the standard and of the new material may be welded consecutively and pulled apart, and slug size examined and compared.

(*Surface Condition*) *Scale.*—Scaly material is essentially bad to spot weld. Hot rolled sections are generally made of easily weldable material, but are often covered with a thick scale which produces a bad weld. It is advisable in this case to shot blast or pickle in order to remove the scale. The difference in the welds both made

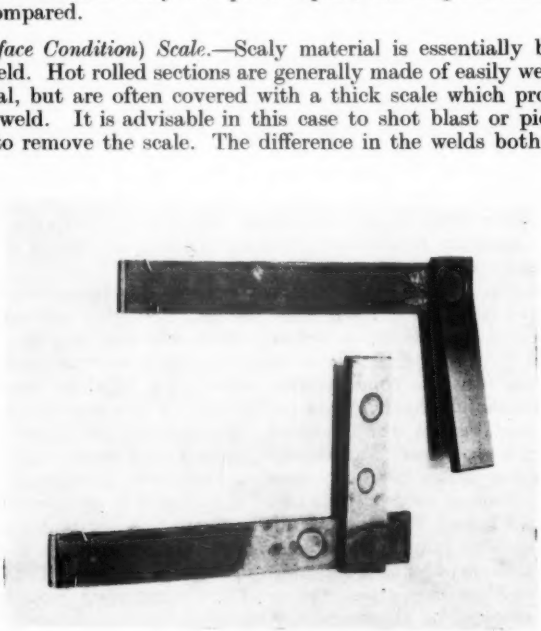


Fig. 4

from the same material, and under the same conditions is illustrated by the photograph (Fig. 4). The first of the two specimens is an excellent example of the high contact resistance effect between the two metals. It simply means that due to high resistance the current density is lowered. The heating current is on for a long time and the outer surfaces have softened, also the weld itself has fused and metal been ejected causing distortion of the parts.

Welding on C.R.C.A. and semi-silver finish gives quite different results. The C.R.C.A. is rolled without pickling off the scale some

of which consequently gets rolled under the surface whilst that with the semi-silver finish is pickled between the rollings. The latter gives the better weld. In the case of aluminiun and its alloys, it is well known that a very thin and tenacious oxide forms on their surfaces. This film must be removed if uniform results are required. Fine emery cloth is useful for this purpose but welding should be carried out within an hour of its use or the oxide film will be back again. (Some welding engineers prefer the use of a motor driven scratch brush). Various oxide removing baths are also in use but they take up room and are rather messy. The film does not return so quickly however by this latter method, perhaps because the surface polish is not scratched up. Users say that several days may elapse between the bath and welding. It is important that the surfaces, particularly of the thicker materials, be reasonably flat and free from corrugations or the welding current will be deflected from its true course to the points of contact of the two uneven surfaces, giving poor welds or burns. High electrode pressures help neutralise this effect but it is better to be sure of flat surfaces.

## Good Design.

That parts of products to be spot welded should be designed for the process is an obvious necessity to every welding engineer. It is, however, unfortunately not always apparently so obvious to the designers themselves. Fundamentally the design for spot welding is the same as that for riveting or bolting except that no holes are drilled. Unfortunately too often parts are designed rather as though they were to be soldered than spot welded.

*Distance from edge of sheet.*—As it is necessary to allow sufficient material around a rivet to enable the joint to resist shearing forces, so it is with spot welding, but if this were the only reason it would not be sufficient because the strength of a spot weld is inherently greater than that of a rivet, for there is no hole in the material. In other words, the two pieces exist at the weldas practically a single homogeneous piece. The amount of material required around a spot weld must, therefore, be determined by another factor namely the mechanical pressure used in the process.

In order to get a clear mental picture of this let us consider some of the changes that take place when a spot weld is made. Imagine two flat discs of mild steel placed one on top of the other. These are placed between the electrodes of the spot welding machine and the electrodes brought together at the centre of the discs. The pressure is applied followed by the welding current. At the adjoining surfaces where the weld is to be, heat is produced sufficient to soften the surfaces and the adjacent region. The surfaces in contact with the electrodes should not get so hot and consequently not soft like the inner ones.

The applied pressure under such circumstances causes the soft inner region to flow together into a homogeneous lens-shaped button, half in one sheet and half in the other, but in view of the cold hard shell of metal completely surrounding it, it is confined and has no outlet. Consequently, it resists the pressure of the electrodes which immediately the current is cut off act as a conductor for the heat in the weld, allowing it to cool, re-crystallise and harden rapidly.

Now suppose this operation takes place very near the edge of the disc. When the hot lens is formed, one side of it, that corresponding to the edge of the disc will not remain hard as in the first case but will soften and the electrode pressure will not be resisted by it, but instead it will be squeezed out at the side. Further distortion will also occur under these circumstances by deep electrode impression. It is obvious that such a weld as this will not be so satisfactory as the one at first described. Its resistance to shear will be small and its appearance ugly.

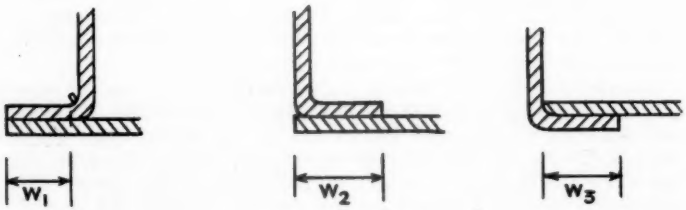
*Flanges, strips, laps, and lugs.*—Flanges, strips, lap joints and lugs designed for spot welding, therefore, should be of adequate width relative to their thickness to guard against this fault. The dimension must of course bear some relationship to the diameter of the weld. An arbitrary equation taking due count of all these factors has been formed and gives very satisfactory results in practice.

$a = d\ (1.0 + 2.5t)$ inches

when a = distance of weld centre from edge of work
d = diameter of weld
t = thickness of material

Then width of strips = 2a
Overlap of lap joint = 2a
Radius of a lug = a

Width of flange or length of lug will be determined by nature of assembly as shown—




$W_1$ = 1.5a—from radius of bend
$W_2$ = 2a—outside of flange or lug
$W_3$ = 2a—inside of flange or lug

Narrow flanges on such metals as aluminium will prove disastrous, it being practically impossible to guarantee welds made on them. Apart from low shear strength and ugly appearance, no uniformity can be guaranteed. The slightest variation of distance of the welds from the edge will cause magnified variations of results and conditions become unnecessarily critical. Whereas small variations of position in the case of reasonably wide flanges do not affect the result.

*Bad location of welds.*—Further points of good design involve the avoidance of placing welds in awkward places. Designers should always bear in mind that in most cases a water-cooled electrode on a support of sufficient strength to resist a high mechanical pressure has to be used and in general welds should not be placed where they create too much difficulty in this respect. The toll in bad welds is liable to be high : maintenance costs due to electrode wear and interrupted production will all add to the sorrows of the production people.

The arrangement of welds on a job in such positions that large and varying masses of metals do not have to pass too deeply into the throat of the machine is another important factor. The variation of the electrical impedance of the welding circuit due to this cause should be avoided wherever possible for it causes corresponding variation of weld strength. In some cases of course especially in coachwork, this condition is unavoidable. The necessity for designers to have knowledge of these matters is too often not appreciated but cannot however be too strongly stressed. No one should attempt to design parts for spot welding unless he has acquainted himself with at least those requirements of the process that are affected by the design.

## Good Equipment.

The equipment required for spot welding consists of machines, electrodes, and fixtures. The requirements in each case will be determined by the nature of the work.

*Machines.*—There are numerous suppliers of reliable spot welding machines in this country and it is often difficult to choose between them. A few general remarks may be helpful, however, regarding this most important matter.

At the outset it is advisable to choose a machine with ample available power. In general the best results are obtained when high current is passed through in quick time under a high pressure. Now, of course, some qualifications are needed here because machines are built capable of handling up to 750 K.V.A., also machines are in daily use in which the welding energy is passed through in one-huudredth part of a second and pressures are sometimes used up

to 10,000 lb. on the electrodes. Again, the range of cost of machines is extremely wide from a few pounds up to £2,500 to £3,000 for a single weld machine.

For general purposes where fairly thin mild steel is used there is a very useful governing factor which helps one to decide upon a certain class of machine. Experience shows that it is not necessary in this class of work to weld in quicker time than one-tenth of a second. Now this speed is of the same order as the high limit at which mechanical contactors will give satisfactory operation, and mechanical circuit breakers in a welding machine are an element that directly contributes very greatly to cheapness of cost. Further, the fact that a weld cannot be guaranteed satisfactory at a higher speed on such a machine enables the manufacturer to limit the capacity of his transformer to suit this timing and this, therefore, also limits the cost.

Machines are built with capacities ranging from half-kilowatt upwards and these small capacity machines are used in great numbers for very small work such as thermionic valve manufacture and in dentistry, etc. These are, however, highly specialised industries and we will pass them in favour of the more general classes of work, work in which parts to be welded consist of sheet metal from 22 gauge upwards.

A good class of machine of not less than 10 K.V.A. is suitable for these fairly thin gauges when say M.S. is to be welded. Up to about 18 gauge material these machines give excellent service because they can be used in the short welding time of about one-tenth second already mentioned, but for the best quality of weld it is important that electrode pressures of 400 or 500 lb. be used. This means, of course, that power operated machines are required.

Many machines of this capacity and even much higher are built to be foot operated with spring pressure but one has only to compare the welds made by the two classes of machine to appreciate the difference. It is obviously a question of quality and on work with long runs of spots, speed considerations count, for with power operation, speeds of 150 spots per minute of uniform welds are easily attainable with comparatively small operating fatigue.

Machines operated by air pressure, with the cylinder immediately over the head, are unquestionably the most satisfactory, and they have the advantage that a pressure gauge can be placed in the air cylinder itself right in front of the operator, and by means of a reducing valve any predetermined pressure can be set up and maintained. This type of machine is a real machine tool, when built with a precision head slide directly driven by a piston operating from a cylinder above it.

The importance of considering the spot welding machine as a precision machine tool is a matter that is becoming steadily recognised. The demand for accuracy in modern industry is becoming more and more strongly felt in this field as the process develops. The days are not far away when only the small shop without compressed air supply will use the foot operated spring controlled machine.

### Modernising Old Machines.

The redesign of some very old rocking arm, foot operated machines rated at 10 K.V.A. is a story of some interest. The rocking arm was made a fixture and reinforced with a stiffening bar. The pedal gear and spring control were scrapped. To the end of the now fixed arm an air operated vertical head was attached, complete with piston and pressure gauge. Connected pneumatically to this head was an electric pressure switch with a control permitting it to make contact at any pre-determined head pressure. The closing of this switch caused the main contactor to close the welding circuit. At this moment the magnetic relay took control—opening the main contactor when the weld was complete. A reducing value controlled the air pressure in the head and the rate at which the top electrode descended was controllable with a needle valve. The conversion of one of the machines gave a flexibility of control which made it possible to record and accurately repeat any desired set-up. The merits of this were immediately appreciated, and the rest of the veterans were re-built and are performing splendidly.

### Tongs.

For structural work on cumbersome parts such as motor car bodies and chassis, railway coaches and even the fabricated girder welded in situ on certain types of building structure, portable types of tongs embodying the features mentioned are in common use. Some of these tongs are operated by hydro-pneumatic heads developing pressures from 1,000 to even 10,000 lb. for heavy work and $\frac{1}{4}$ in. thick angles and channels are not infrequently spot welded where once rivets were used. The very high pressures are needed in order to ensure contact of the parts on materials that are not necessarily flat or entirely free from scale.

It is important to state that only machines of unimpeachable quality will maintain a good production under such exacting conditions.

### Impulse Machines.

For some of the more critical materials such as aluminium-copper alloys extremely elaborate machines have been developed particularly in France and now also manufactured in this country in which an endeavour has been made to reproduce the effect of cold

working to restore the physical properties of the material which the heat of welding tends to destroy. In these machines, apart from an ingenious method of current supply, the pressure of the electrodes is at first high in order to ensure good contact. It is then reduced in order to give a sufficiently high resistance to generate welding temperature, followed by a high pressure giving a forging effect. The high pressure can be maintained until the work is quite cold. The result is a veritable aristocrat among spot welds, and its quality is such as to satisfy the exacting demands of aircraft inspectors and moreover to stand up to active service without faltering.

## The Controller.

This very important piece of apparatus is the brain of the machine. Its function is to control the welding period and according to the type of apparatus so does its method of doing this vary. They may cost from a few pounds to several hundreds of pounds and in general their accuracy increases as the price.

The chief types are as follows :—

(1) *Magnetic relay types.*—This type usually operates by means of an induced flux due to the current in the welding circuit—when the current has attained a pre-determined value the relay throws out the main contactor and this ends the flow of welding current.

(2) *The Watt meter type.*—This is similar in design to the ordinary watt hour meter with the rotating aluminium disc, whose rotation speed is controlled by the strength of field determined by the energy consumed in the weld. Attached to the spindle is a contact whose distance from its counterpart is adjustable—the contacts therefore make when a pre-determined quantity of energy has been expended.

(3) *Thyratron.*—This represents that class of controller operated by mercury discharge tubes. They commence operation on a definite part of the A.C. cycle, and finish at the end of a pre-determined number of cycles. They are therefore purely " timers " but their accuracy is unimpeachable.

All these types of controller can be operated with mechanical contactors which add an error due to lag and sometimes " arc draw." Or they can be used with ignitron type tubes—these are discharge tubes and have therefore no lag, either mechanical or electrical.

(4) *Full Thyratron controller.*—This type uses the Thyratron controller similar to the type already mentioned, but it controls the impedance of a choke in series with the primary of the welding transformer. When the choke is acting as an impedance it reduces the energising current in the transformer to a negligible quantity,

but during the accurately controlled discharge period the impedance of the choke is reduced to zero by the discharge current, thus permitting the welding current, to flow during that time.

The choice of a controller must of course be determined by the job for which it is required : In general the alloys of the duralumin and stainless steel class need the accuracy and short times of the full Thyratron controller. For ordinary aluminium, a Thyratron or fast watt meter controlled contactor is suitable. Mild steel however, is generally safely welded with a good magnetic relay type controller.

**Electrodes.**

The best machines obtainable will not produce the results for which they were designed unless the electrodes are of a quality equal to the task. No engineer will risk his reputation by spending several hundred pounds on a machine tool unless he is prepared to furnish it with good quality, well designed and properly maintained tools in order to get the best work out of it. In every well organised factory, the tools applied to these machines are most carefully selected or designed and then as carefully looked after by an efficient tool room organisation. The time is fast approaching when the much abused and almost neglected spot welding electrode will receive the same consideration as any other tool in the establishment.

*Material for electrodes.*—The ideal material for electrodes has not yet been found. It needs the highest possible electrical and thermal conductivity and at the same time a resistance to the high pressures of the modern machines. Electrically the ideal metal is pure silver with pure electrolytic copper following as a close second. These metals are extremely soft but can by work hardening be made quite useful and resistant under good conditions.

The slight electrical advantage of silver scarcely warrants its extra expense. For aluminium and its alloys and stainless steels excellent practical results back up the theoretical considerations supporting the use of pure electrolytic copper. In order to appreciate this, a brief consideration of the nature of a spot weld in duralumin will not be out of place.

A section through this weld will show that a lense shaped centre has fused together the two pieces but that the outer surface has not been allowed to become hot. In the case of the duralumin class of alloys this conditions is absolutely essential and it is preferable in all materials. Such a condition indicates that during the welding period an exceedingly steep temperature gradient existed between the outside of the lense and the surface. Now such a condition could only exist provided the surface were in intimate contact with

a very cool material with very high thermal conductivity, otherwise the passage of the heat, would, as it were, be choked, and the surface temperature would rise. In addition to deformation of the tip, the tendency to alloying of the aluminium with the copper increases rapidly with the rise of temperature. This sets up a high contact resistance and successive welds are made with increasing temperature at the surface where it is not wanted. The indent, therefore, increases and becomes ugly and what is worse in the case of duralumin, copper gets in the surface which becomes the cradle of corrosion to develop later; also the fused centre spreads to the surface and adds to this trouble. This is the main argument for the use of pure copper.

For mild steels a harder material can be used and many good copper alloys are made for this purpose, e.g., copper cadmium, copper chromium, copper beryllium, etc., the hardness being determined by the proportion of the auxiliary metal, and the heat treatment. The electrical and thermal conductivity are generally reduced by this addition, but as the irons and steels, have themselves a rather high resistance, this is not a very great disadvantage.

With the right materials used for properly designed electrodes properly maintained, an excellent quality of weld can consistently be produced. There is no excuse for the very ugly welds one so often finds on commercial articles. They can be prevented by the exercise of proper precautions.

Special electrode materials are manufactured and have their uses for special types of manufacture. Some of these materials are extremely hard and have low thermal and electrical conductivity. The ideal spot weld cannot be made with these materials, but they serve their purpose by enabling one to weld where it would be extremely difficult without them. A case comes to mind where a copper wire had to be welded to a nickel one. The high thermal conductivity of the copper made it difficult to raise its temperature to the welding point by use of copper electrodes, but by using a copper electrode against the nickel, and one of tungsten against the copper, the weld was successful. This combination obtained a better balance of temperature in the two metals because the excess heat was conducted away through the copper electrode, while the heat in the copper wire could not be conducted easily through the tungsten, but remained to heat it to the welding temperature.

*Design.*—The design of electrodes is of equal importance with the material from which they are made—the chief factors being design of tip, size of body, and the water bore. Sufficient has been said to indicate that in general one of the prime functions of the electrode is to carry the current unimpeded to the location of the weld. In order to do this the electrode should have as large a cross sectional

area as possible and should taper fairly rapidly towards the tip where the current has to be concentrated.

*Design of tip.*—For the best and most consistent results, the tip should have a definite design and be maintained in its original form and dimensions. Arbitrary laws based on required shear strength exist for the size of rivets and as the analogy between a rivet and spot weld is so strong and the function of the two identical, it seems reasonable that the sizes of each should bear some ratio to each other. It has been said that generally size for size a spot weld is somewhat stronger than a rivet.

Assuming good conditions the size of a spot weld is determined by the size of the electrode tip and as the size of the rivet is determined by the thickness of the sheet, so the tip diameter should be determined in the same manner. As the result of experience and theoretical considerations, a simple expression has been evolved which relates the size of the tip to the sheet thickness.

Tip diameter $= (.1 + 1.6t)$ in.

thus on the very thinnest material the tip cannot be less than 0.1 in.

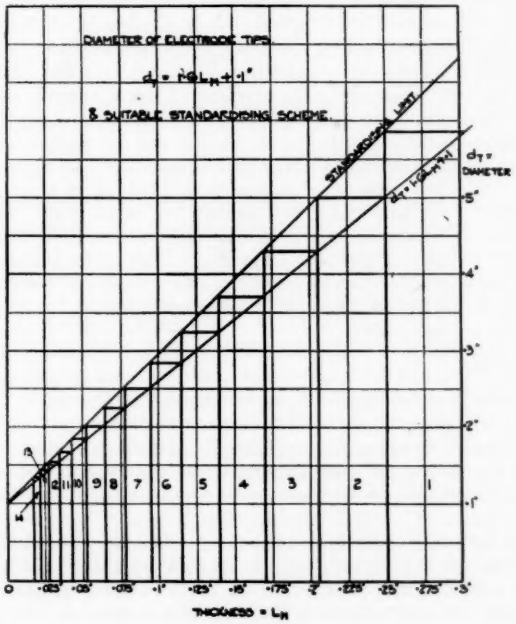



Fig. 5

According to the formula this of course means a different size of electrode for every material used, and is satisfactory only where the range of materials is limited. In cases where the range of material thickness is very wide, a limited number of standard sizes can be used. Any one of these can be applied over a certain range of thickness. (Fig. 5).

If two unequal thicknesses of metal are to be welded the law still applies :—

e.g., if one sheet of $^1/_{32}$ in. has to be welded to one of $\frac{1}{8}$ in., then the tip against the thin sheet will be .150 in. diameter and that against the thicker .30 in. diameter.

In such a case if the electrodes were of the same size the one on the thinner sheet would allow more heat to be conducted away than the other one because the welding heat is nearer to it. The weld would, therefore, not penetrate deeply enough into the thinner sheet—perhaps with disastrous results the different contact areas of the tips tends to balance the weld penetration.

Another case when two different sized tips may be used is when an unmarked surface is required. A large flat tip may be used on the smooth surface and a standard size opposing it.

It is not advisable in production to have two flat ended tips because any discrepancy in the surface of the material may cause only a local contact—or even if the surface is good it is very difficult to guarantee that the total area of the tips will contact evenly with the sheets. A slight dome is good practice and this may have a radius of 2 or 3 in., but whatever radius is decided upon it is good to standardise it. These rules can be applied with good results to every kind of material, but it is only fair to mention that some authorities stress the use of a cone shaped tip for aluminium with an angle of about 166° or in specific cases where one electrode has to be flat in order to leave an unindented surface about 150° is sometimes recommended.

**Water Bore.**

The water bore should be brought as close to the tip as possible and $\frac{3}{8}$ in. to $\frac{1}{2}$ in. is a useful practical dimension as this leaves plenty of metal to allow for repairs. The diameter should be ample to allow for the water feed tube to enter freely and the area for return water should be at least equal to the area of the feed tube bore.

It may be mentioned here that the design of electrodes should be such that when they are fixed in the stakes the feed tubes should reach to within $\frac{1}{4}$ in. of the bottom of the electrode bore. Some trouble may be experienced if due care is not given to this matter. A tube that is too long may bed on the bottom and prevent the

water flowing or one that is too short may allow a pocket of residual water to form which if overheated may become steam and again prevent the water flowing on account of its back pressure.

**Jigs and Fixtures.**

As a first principle of design, jigs holding parts for spot welding should be independent of electrodes. Where the electrode is designed as in integral part of the jig it is often difficult to maintain and is liable to lead to faulty locating of parts. It is preferable, if possible, to use standard electrodes and to design the jig to be used in conjunction with them. Sometimes this may require a little co-operation with the designers of the parts to be welded in order to obtain a design that can be applied to a well designed jig.

Generally jigs should not be made of steel, especially if they are to surround the weld, because it is not advisable to have a ring of magnetisable material around the secondary circuit. A large jig of this type can materially influence the impedance of the circuit. Moreover, a jig of non-ferrous metal in the form of a closed circuit may become hot in use due to eddy currents. A little care may save a lot of money and worry.

Jigs should be electrically insulated between the parts that contact with the two individual pieces to be welded, or partial short circuits will occur, draining the weld of its necessary current and producing a variable that may lead to serious troubles. Once these principles have been recognised the design of jigs can be safely left to a good tool designer who has been trained to appreciate them.

*Good technique.*—The foregoing remarks have been made with the object of showing the way to the production of good welds, but, with the best intentions in the world, it will not be possible to maintain consistently a high quality of welding without organising against the production of faulty work, which is likely to stain the reputation of the product.

A well organised control of the process is the strongest protection available against this evil, and the remainder of this paper is written with the object of outlining the sort of control that is necessary.

*Operation planning.*—Whatever the sytem of operation planning used in the factory it is advisable to do more than merely specify " spot weld " as an operation as through this were something as elementary as the operation " assemble nut on screw " or " file off rough edges." In my company a specification is issued for every part that is spot welded. A specimen of this specification is the subject of the diagram Fig. 6. It will be seen that the job represented can be done on either of three machines, and that all the controls of the machine are calibrated and indicated on the specification. The air pressure in the cylinder head is indicated in lbs. per square inch.

The tapping of the transformer is given, the settings of the controller, the distance apart of the electrodes when the head is up, the rate at which the top electrode closes on the work, the head pressure at which the welding current is switched on. The electrodes and stakes to be used and even the manner in which they are to be set up.

WELDING SET-UP

W.S. - LP 63879-81

DATE

LP - 63879-81

Spot welding bracket to side & plate cover

| | | | |
|---|---|---|---|
| MACHINE | 488 3 | 488-4 | 488 5 |
| PRESSURE P.I. | 40 | 40 | 40 |
| " P.C. | | | |
| VOLTAGE | F.I | F.I. | F I |
| CONTROLLER | 30 | 100 | 100 |
| TORDIO | 1-5 | 1-4 | 1-4 |
| AIR PRESSURE SWITCH | Normal | Normal | Normal |
| CYCLE CONTROL 50 CYCLE | | | |
| " NO SHELL | | | |
| " A.I. | | | |
| " A.I. & PIC. | | | |
| ELECTRODE DROP | 3/16" | 3/16" | 3/16" |
| DROP SPEED | Normal | Normal | Normal |
| FIXTURE | | | |

| | TOP | BOTTOM |
|---|---|---|
| STAKE HOLDER | 384 - 122 A | 384 - 122 A |
| STAKES | 384 122 | 384 - 147 |
| ELECTRODES | T98 - 37 | T98 - 223 |
| SET-UP | | |

Note - Spots must appear neatly in centre

APPROVED - C. Young

Fig. 6

*Setter's duties.*—The function of the setter is simplified to collecting the electrodes and jigs from the tool store and setting them up exactly as specified. This is a routine job and on work of a light type can be entrusted quite satisfactorily to an inteligent female setter.

Once the job is set up the setter makes the first weld and submits it to the inspector, and if it is passed the job proceeds. If it should not prove to be a satisfactory weld, the setter calls in the aid of the planning engineer whose job it is to find out what is wrong and get it

put right. It is understood, however, that the settings on the specification must not be altered. They, like the laws of the Medes and Persians, do not change. This enables us to detect faults in machines and even in materials that might not otherwise have come to light. One case come to mind where a good weld could not be produced by the proper set up and investigation showed that the parts had been made of the wrong grade of mild steel. Thus, the welding technique had actually rejected the wrong material.

The function of the setter does not end with setting up the machine but he is responsible for seeing that all the conditions required by the specification are maintained throughout the running of the job. He must be constantly on the alert for any changing conditions, that water flow indicators are functioning, that air pressure remain constant, and particularly to watch electrodes and change them when they have worn to the limit of diameter indicated on his check gauge. By this means current density can be kept within practical limits on every weld. His function is to see that worn electrodes and all jigs when not in use are submitted to the tool inspection for routine examination.

A well organised raw material inspection department will keep control on raw material quality, and the setter should call in the inspection department if work that is brought for welding does not seem to him up to the usual standard of quality. Machines should be maintained in good condition by routine check over by competent persons. Circuit breakers, contacts, and current contacting faces should be always maintained clean and bright. Stakes and holders should not be allowed to get dirty as they will increase the resistance of the circuit, and sliding heads and pistons should be examined for freedom of movement.

Spot welding when carried out under proper control will give results that leave no doubt in the minds of those responsible for producing a good quality job and the cost of producing good welds will be more than balanced by the good will of a satisfied customer.

It is, of course, out of the scope of this paper to consider any of the associated methods of resistance welding such as projection, seam, butt, or flash welding, nor has it been possible to deal with the many varieties of welding and even brazing that are often performed on spot welding machines, but it is hoped that what has been said indicates that controlled spot welding is a reliable process in normal production, and that although whilst a weld is being made, physical changes are taking place in metals under exacting conditions, yet those changes are made according to infallible natural laws, and every modification made in any one of the conditions will be interpreted by those laws in modified results. Hence, the importance of keeping every possible variable under strictest control—no matter whether it be the quality of the material itself, the current, pressure

and time, or that more elusive factor, the human element. The better the control over all these variables, the more nearly will the ideal " repetition " weld be approached.

The following are nine golden rules of spot welding and their observance will find a way out of many a trouble :—

(1) Be sure machines have adequate electrical power, electrode pressure, controlling, and indicating devices.
(2) Maintain the area of electrode tips within controlled limits.
(3) Use electrodes with ample cooling and current carrying capacity.
(4) Organise efficient maintenance of all spot welding equipment.
(5) Use only clean surfaces both on work and electrodes.
(6) Foster co-operation between designers, planning, and welding engineers.
(7) Keep spot welds a safe distance from the edge of the work.
(8) Treat electrodes and jigs as separate tools whenever possible.
(9) Always set up the same job in the same way. A faulty weld detects a faulty machine or material.

## Discussion

MR. FINLEY: I think there is quite a lot of information which would be valuable to us on the different materials that could be welded to one another.

MR. LENG: The question of welding dissimilar materials is a very big one and a very dangerous one. Whilst there are quite a number of materials that can be spot welded together, one has always to be very careful in that matter, because of the possibility of welding together materials that, having been welded, may fall apart at some later date due to ageing, corroding, or some other peculiar phenomenon taking place. Certain materials are frequently welded together, such as the one I have quoted, copper and nickel. Metals like tungsten and nickel are welded, and brass has been welded to steel: but with regard to the welding of brass to steel, we have generally found that it is more the brass that is fused than the steel. They do not join too well.

There is one very important factor in regard to the spot welding of dissimilar metals, and I have just touched upon that in the paper, and that is the fact that the metals have different characteristics. Because of that, particularly the thermal and electrical conductivity, they very often require different electrode materials on each metal. You might require an electrode of fairly low electrical conductivity against a high conductivity metal, and vice versa. For those who are interested in that subject there is a table given in a book published by Mallory's, the electrode material manufacturers, which gives a list of pobably a couple of hundred combinations of different metals that they consider can be welded together, and they specify the materials which should be used for each case, and the physical conditions of the materials they use, when studied, will show how they apply the laws which we have mentioned of putting a low conductivity metal against one of high conductivity.

Until quite recently it was thought that the reason why a weld took place at the junction of the metals was because of the contact resistance of the metals. That is a fallacy. If you make a weld in two pieces of material, say $^1/_{16}$ in. thick they will weld at the junction of the metals, but if you also carry out exactly the same operation on one piece of metal $\frac{1}{8}$ in. thick you will get a mock weld in exactly the same position, and what causes the weld to take place —assuming that we have two metals of equal thickness—at the contact surfaces of the two metals is this fact: that if you take the area upon which the electrode actually makes contact with the metal and project that area through to the other electrode, there will be a cylinder of the metal you are wanting to weld between the two.

That cylinder of metal has definite electrical resistance, and when the current passes through, heat is generated according to the resistance of the metal lying between the two. An equal amount of heat is generated throughout the whole of that material between electrode and electrode, but in view of the fact that the electrodes have a high thermal conductivity they take away the heat from the centre down to the electrode surface, as I showed on the first diagram we projected on the screen, so that the only part that remains hot is the part in the middle, and that is where the contacting faces are, and where you get the weld. That is why the weld takes place at the centre and not at the outer surfaces. It will, however, take place just as much at the outer surfaces if the electrode conditions are bad enough.

MR. ELLIS: Mr. Leng has got everything else down in useful formulae relating to the thermal conditions, and perhaps he could help me on this point. There must be a point of minimum width in relation to the thickness of the metals. I have in mind some very narrow parts which when welded are constantly falling off, and it strikes me that there must be some sort of relationship there.

MR. LENG: I have already treated that matter, Mr. Ellis, if I can find it in these notes, I refer to a slide which gave a formula for the distance of the weld from the edge of the sheet, and that formula was $a = d\ (1 + 2.5t)$. Now if that is the distance of the weld from the edge of the sheet, with two edges one on either side of the weld, the width of the strip in that case will be twice "a."

A MEMBER: There is just one question I would like to ask with regard to the weld while it is being done. We have just invested in a spot welder, and we find we only get a decent weld if the metal around the tip becomes incandescent. According to the slide shown the metal should not heat up at all at the tip. It should be reasonably cool and discolour, but it should not get to incandescence. We have been welding $^1/_{16}$ in. to $\frac{1}{8}$ in., and we find we have to get a spot as big as a farthing round the tip before we can get a reasonably strong join. Am I correct in interpreting your remarks that we should be able to get a weld that is sound by waiting only until the top of the surface discolours? I am referring to mild steel.

MR. LENG: I am afraid with regard to metals of a very high resistance like mild steel you will never be able to make a weld without some ring of discolouration around the electrode. In general where the electrode actually touches, the surface is not discoloured, but there is a halo effect around it which is small or large according to the length of time the current flows. Generally for about $^1/_{16}$in. material I should say it would be very difficult to get a weld without a halo of at least $^1/_{16}$in. wide around the electrode, but not actually contacting with it. The tendency of the zones of

equal temperature near the surface is to follow almost parallel to the contour of the electrode face and they will therefore appear on the top surface as a ring or halo surrounding it. You will not avoid that. The slides I showed where there was no sign of it was in duralumin. Yes! Always in mild steel except where large area electrodes are used on one side of thin sheets in order to prevent it. It should not come up to white heat. Sometimes it will only just reach a dull red heat. I do not think you need to be too alarmed about this heating effect so long as it is not excessive. The great thing is—and this is the golden rule with a weld of this type—if you like to press the electrode with the finger right close down to the work while you are making your weld, the electrode should be cool enough to enable you to do this, and when your electrode comes away you should still be able to hold it because it should be perfectly cool: it should never get hot. Providing your electrode is cool it will limit the size and temperature of the hot ring. Of course on thicker material it would not be possible to keep the electrode so cool, this is one reason why electrodes wear more rapidly under these circumstances.

MR. ————: There is just one point on which I would like information. In your nine points on spot welding you mentioned that the surfaces should be clean. Would you consider press parts which have just come from the presses clean enough, or do you advocate finishing for spot welding?

MR. LENG: I think parts coming from a press shop are in general clean enough for spot welding. Oil does not seem to affect it very much, but if there is a lot of dirt then it is necessary to have another operation. Of course there is always the point that one does not like to have greasy work near spot welding machines. It is an advantage to degrease before welding as it is best to keep the job clean, but it is not really necessary from the welding point of view.

MR. ————: In your illustrations this evening you showed a cover with two metals being joined together. Is it at all possible to weld three materials simultaneously on three surfaces? If the surface has been chromadised or sheradised or has had some other treatment to the surface, has that an adverse effect on the weld?

MR. LENG: The welding together of three pieces of metal is quite possible and is quite a common practice. I think I have seen as many as 20 pieces welded together, superimposed on each other. It is quite satisfactory. With regard to welding on sheradised and other processed material, the great thing to be considered is—is the process one which produces a refractory coating, or one with a very high resistance? If it is equal to an insulation then of course the current will not pass through, but it may be an insulation which

you can actually break down by the electrode pressure, and then you are liable to get exactly the same effect on the weld as you would with scaly material, and it is liable to cause physical changes which will make the weld porous. There are one or two points with regard to this matter which are rather interesting. For example, regarding the phosphate coatings which are sometimes used, a weld can be made and the work can be coated afterwards, but the coating will not be effective on the oxidised part that has been left by the weld, so that you will have, where the weld is, an oxide coating gradually going off to a very thin film, and then the phosphate coating or whatever coating has been used, will meet it in a thin film at its boundary; there is always the danger and the risk that at that junction there may be rust or corrosion set up.

MR. ————: Mr. Leng in his discussion on the relative strength of riveting and spot welding mentioned, I think, just a little to my surprise, that the strength of a spot weld would be greater than that of a rivet. I do not quite know how many agree with me, but I wondered whether Mr. Leng had in mind the possible reduction in strength caused by the effect of having to punch a hole through two parts in order to put the rivet in, and whether this would be to the credit of spot welding. At the same time, when you are talking about the size of electrodes at the tip being equal to the diameter of an appropriate rivet, the diffusion area of two pieces put together seems if anything rather less than that diameter, and I wondered whether it would be safe to take the appropriate rivet diameter as equal to the diameter of the electrode which should be used, and say that the strength of the welded join would be greater than in the riveted join.

MR. LENG: That raises rather a big question and certainly an interesting one. There are two questions really there. One is the relationship of the weld dimension to the tip dimension, and the other one is the question of the strength of a rivet in its relationship to a spot weld. I think taking the last one first, although I have never actually made any measurements myself—I am merely quoting people who have—it has been stated that size for size a spot weld is some 25% stronger than a rivet. Never having checked on that I cannot say, but I should think it is quite feasible that it should be so, in view of the fact that there is no hole to tear; but that must be size for size. It must be a rivet diameter of the same size as the diameter of the weld and not as the diameter of the electrode. That brings me to the first part of the question—the relationship of the size of the weld to the electrode. That is a varying matter, and it varies according to the electrical conditions under which the weld is made, and it varies also with the thickness of the material. For example, you can use quite a large diameter electrode on a very thin piece of steel, and to your astonishment

your weld will be about as big as the diameter of a pin. For quite a long time I was puzzled as to why that should be the case, particularly in view of the fact that when using the same diameter electrode and welding a thick piece of material you can get a weld that is greater in diameter than the electrode. The thing seems so utterly inconsistent, but I think the answer to it lies in the fact that in very thin material when your electrodes press against it it tends to buckle outwards, and the two metals only touch practically on a pin's point, but in the case of the thick metal they do not do anything like that at all, and the thicker the metal is the more the tendency of current passing through to diffuse and make a barrel shaped passage between the electrodes and it is the boundary of the barrel that determines the dimension of the weld.

A MEMBER: I have in mind a job in which we had to spot weld two parts together and subsequently case harden, where one part needed to be hardened but not the other, and so we copper plated that part first. I would like to know whether Mr. Leng considers the difference between the two materials has a detrimental effect on the weld.

MR. LENG: There again it is a particular subject that I have never had any actual experience in. I should think, however, that there would not be much harm in it, because I should imagine if sufficient heat were generated at the point where you want to make the weld, the copper would all have been blown away before the welding actually took place.

A MEMBER: One point in your lecture was particularly interesting to me, and that was the size of the tips. You do not state whether different sizes were used for different materials, and whether for ordinary mild steel or .6 or .8 carbon content you would increase or decrease the size of the tips. The second point I would like to make is, having committed the crime of making welding jigs in steel, I would like to know whether there is any process like sheradising or bonderising the jigs to prevent some of the losses which occur through making them in steel.

MR. LENG: With regard to the relationship of tip diameter to carbon content, I should not consider that to be a very important matter. As a matter of fact we, in my company, actually use the chart for tip diameters as a standard for all materials. We do not make any reservations. I believe with some of our aluminium work we do use a different electrode, but that is rather a special case. With regard to any process being applied to a steel jig to make it non-magnetic, I do not know of one. The only thing would be if you could use a steel of sufficiently high carbon content to get it into an austenitic state and keep it there, it would be non-magnetic, but I do not think that is practical.

A MEMBER: You state that the copper might spill out between the two sheets of metal whilst welding. Would it be the same in the

case of welding two galvanised sheets together ? Would the spelter between the joined surfaces spray out in the same way, because I have made some joins and I am afraid of corrosion on the outer side of the plate.

MR. LENG : Yes, it does tend to splash out and at the same time there is a tendency towards making a brittle joint ; and there is always the danger of corrosion taking place if the work is to be used in a job where galvanising is absolutely essential. If you were to open the weld you would find that you had a steel or iron face exposed to air. One of the chief troubles is not generally so much that point, because that is generally taken care of by finishes, but it is the fact that welding on that type of material has a bad effect on the electrodes themselves, and galvanising plays havoc with their surfaces, and tends to alloy with them, and causes rapid electrode deterioration. Tin plate is in the same category.

A MEMBER : Having had some experience of welding high carbon content steels, when the weld has been broken, I have found that it seems to be crystallised. Is there any reason for that ? Can you give me any reason ? You have only to drop the two welded pieces and they fall apart : that is with .8 carbon content steel.

MR. LENG : I think .8 carbon steel is definitely bad stuff to attempt to spot weld. The trouble is universally experienced, and not being a metallurgist I do not know that I can give you an answer to it ; but it has always been found that when you have a high carbon content you do get trouble with brittle welds. The same thing applies to some of the harder types of steels that are used, such as the tungsten steels and chromium steels. I had a case of one weld in a cobalt steel which when it was broken actually left the weld fastened like a dome to the other half, but it had come away perfectly clean, showing that not only was it a brittle weld, but it had actually split along the heated boundary and had come out as a perfectly clean piece ; and the same thing will apply at times with regard to high carbon steels. It is best to avoid trying to weld some of these materials if you can possibly do so. They are not satisfactory for welding.

A MEMBER : I am only a visitor but as a fellow specialist on spot welding I should be glad to offer a further word.

The reason for the breaking of carbon steels is purely that which we find in the case of an ordinary chisel or any other tool which is quenched and afterwards heat treated. Unless the weld is afterwards heat treated in the manner in which the makers indicate for the particular steel used it is impossible to regard it as an effective junction at all. We have found that any steel which has over .2 carbon content is definitely what we call unweldable as a practical proposition, unless it goes through the complete heat treatment for that material.